UCR College of Engineering- Center for Environmental Research & Technology

2013 DOE Vehicle Technologies Program Review Presentation

Next Generation Environmentally-Friendly Driving Feedback Systems Research and Development

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Project ID #
VSS086

Overview

- ***Timeline***
  - Start 10/1/2011
  - End 9/30/2014
  - 40% complete
- ***Budget***
  - Total project funding
    - DOE – $1,210,235
    - Contractor – $665,472
  - DOE funding in FY12
    - Received $706,265
    - Expended $389,496
  - DOE funding for FY13 (as of January 31, 2013)
    - Received $100,000
    - Expended $81,246
- ***Barriers***
  - Public acceptance
  - Safety concern
  - Cost Effectiveness
- **Partners**
  - ESRI
  - NAVTEQ
  - Beat the Traffic
  - Earthrise Technology
  - Automatiks
  - U. of California Berkeley
  - Riverside Transit Agency
  - Caltrans

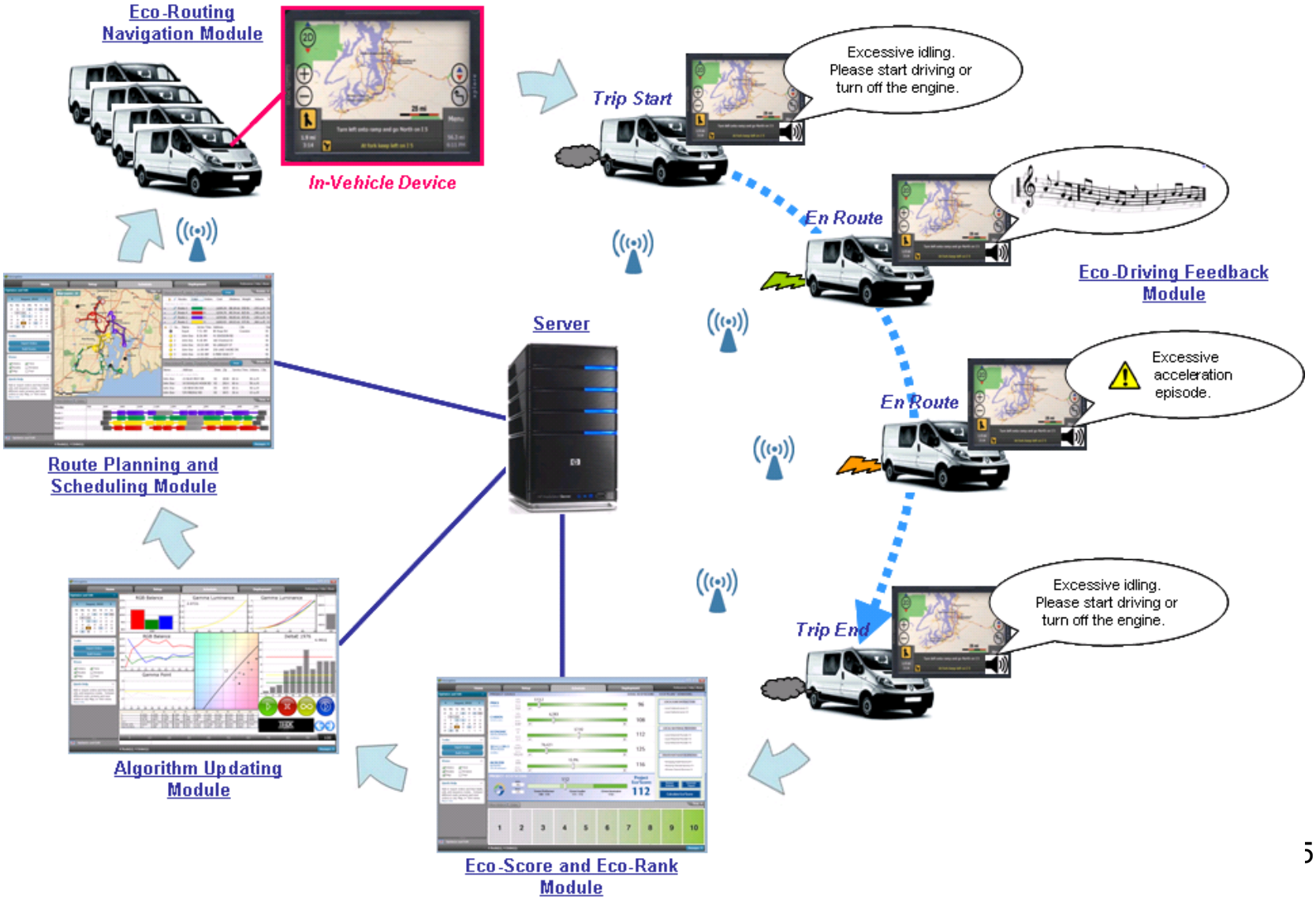
Relevance

- Overall project goal
  - To design, develop, and demonstrate a next-generation driving feedback system that will:
    - Improve fuel efficiency of the fleet of passenger cars and commercial vehicles by at least 2%,
    - Comply with federal safety and emissions regulations, and
    - Deployable across existing vehicle fleets.
- Project objectives over the past year (March 2012 – March 2013)
  - Complete three modules of the system
    - Eco-Routing Navigation module
    - Eco-Driving Feedback module
    - Algorithm Updating module

Approach (1)

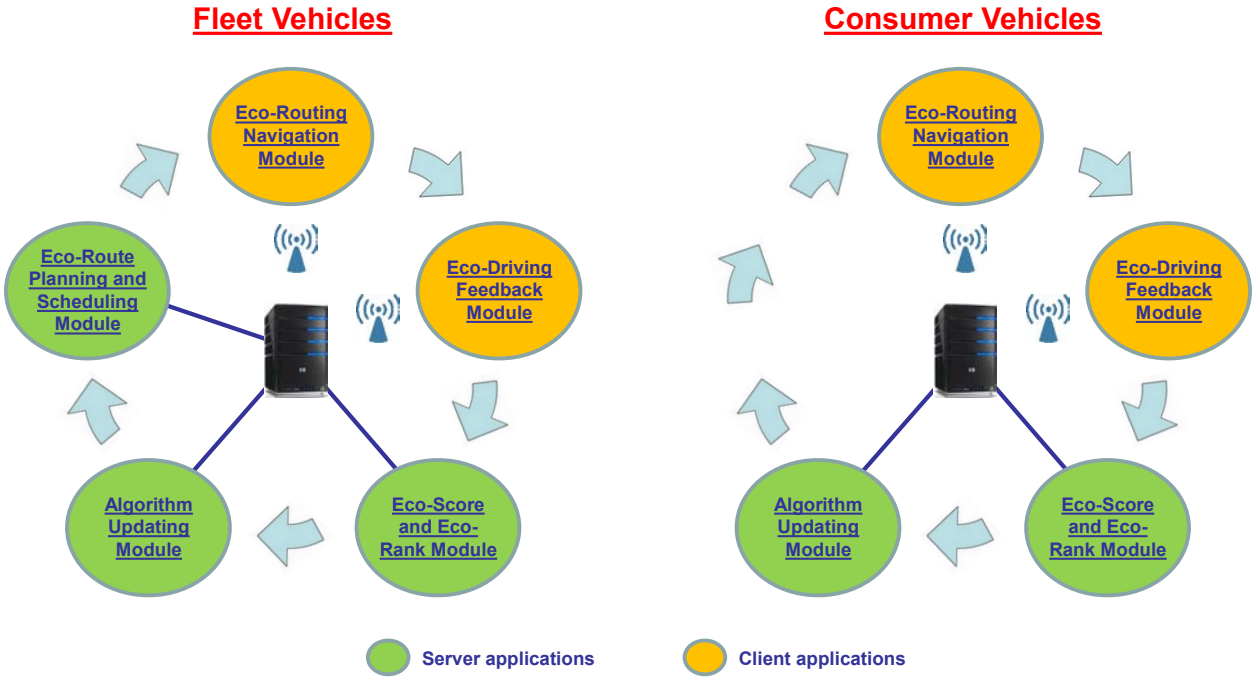
- Offer and encourage fuel-efficient choices to drivers/fleet operators in multiple aspects of their vehicular travel:
  - Eco-Trip Scheduling module allows fleets to plan a sequence of stops (e.g., for delivery) that is most fuel efficient.
  - Eco-Routing Navigation module suggests the most fuel-efficient route from one stop to the next.
  - Eco-Driving Feedback module provides sensible information, recommendation, and warning for fuel-efficient vehicle operation.
  - Eco-Score and Eco-Rank module provides platform for driving performance tracking, self-evaluation, and peer comparison.
- Fuel savings from individual modules can add up to a significant amount of savings.
- The modules make use of real-time information, high-performance computation, and advanced analytics.

Approach (2)


Eco-Routing Navigation Module
In-Vehicle Device
Trip Start
Excessive idling. Please start driving or turn off the engine.
En Route
Eco-Driving Feedback Module
Server
Excessive acceleration episode.
En Route
Route Planning and Scheduling Module
Trip End
Excessive idling. Please start driving or turn off the engine.
Algorithm Updating Module
Eco-Score and Eco-Rank Module

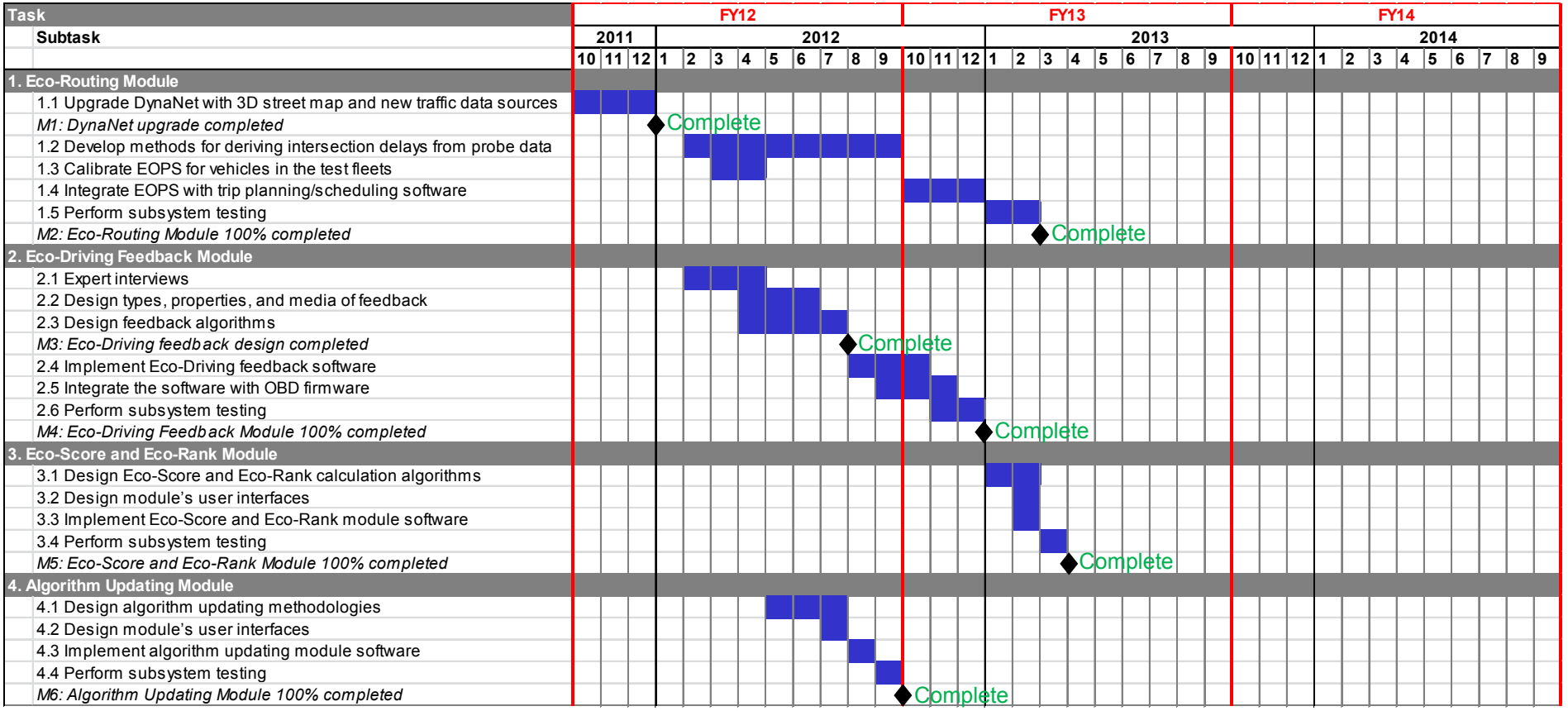
Approach (3)

- The system is:
  - Applicable to both fleet and consumer vehicles
  - Scalable from a few vehicles to a large number of vehicles
  - Compatible with multiple software platforms (e.g., Windows, Android)
  - Customizable due to modular software architecture



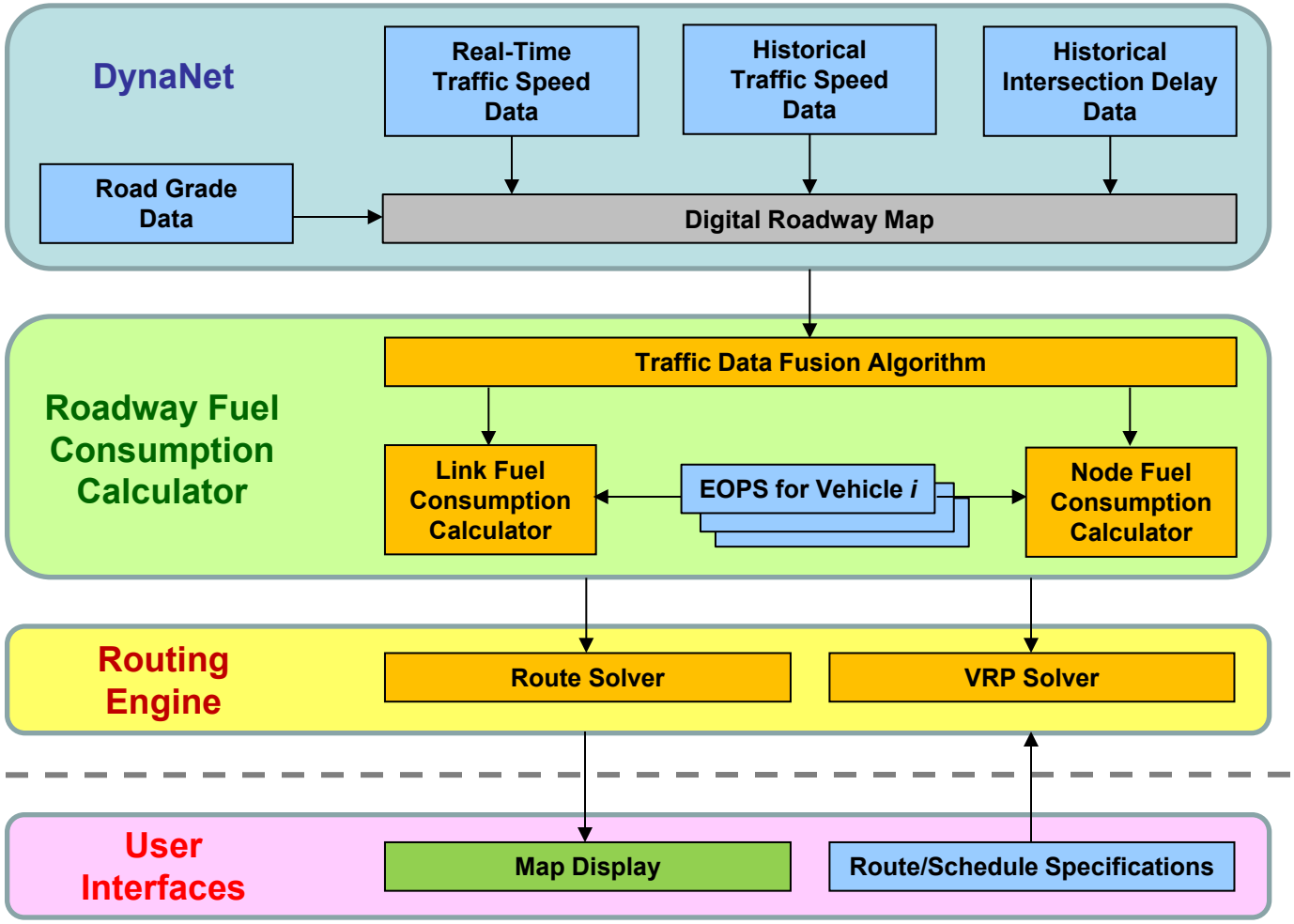
Approach (4)

- Milestones for FY12 and FY13



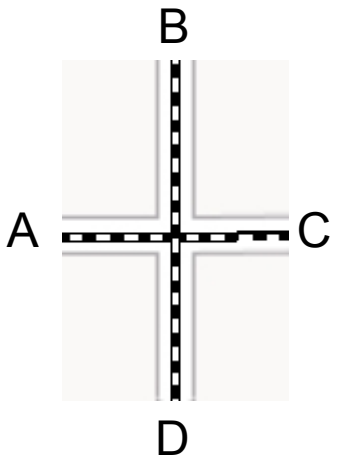
Technical Accomplishments (1)

- Eco-Routing Navigation module – software architecture



Technical Accomplishments (2)

- Eco-Routing Navigation module – intersection delays
- Node costs (e.g., intersection delays & fuel consumption) are typically not accounted for in route calculation.
- They are defined in data structure based on turning movements (e.g., 16 turning movements for a typical 4-way intersection).

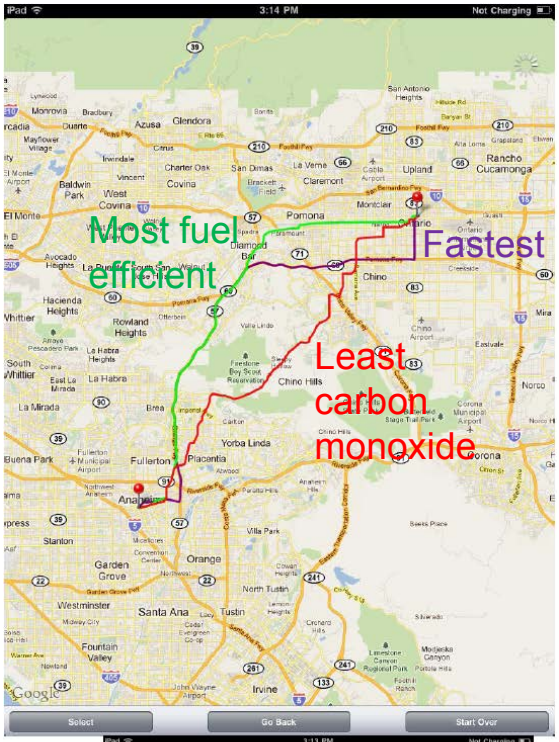


Turn ID	From Link	To Link	Peak Delay (s)	Off-Peak Delay (s)
1	A	A	45	15
2	A	B	60	20
3	A	C	30	10
4	A	D	35	12
5	B	A	12	4
6	B	B	12	4
7	B	C	18	6
8	B	D	10	3
	…	…	…	…

Technical Accomplishments (3)

- Eco-Routing Navigation module – route evaluation
- When considering intersection delays, optimal routes tend to contain fewer turns and consist more of freeway driving.

Without Intersection Delays



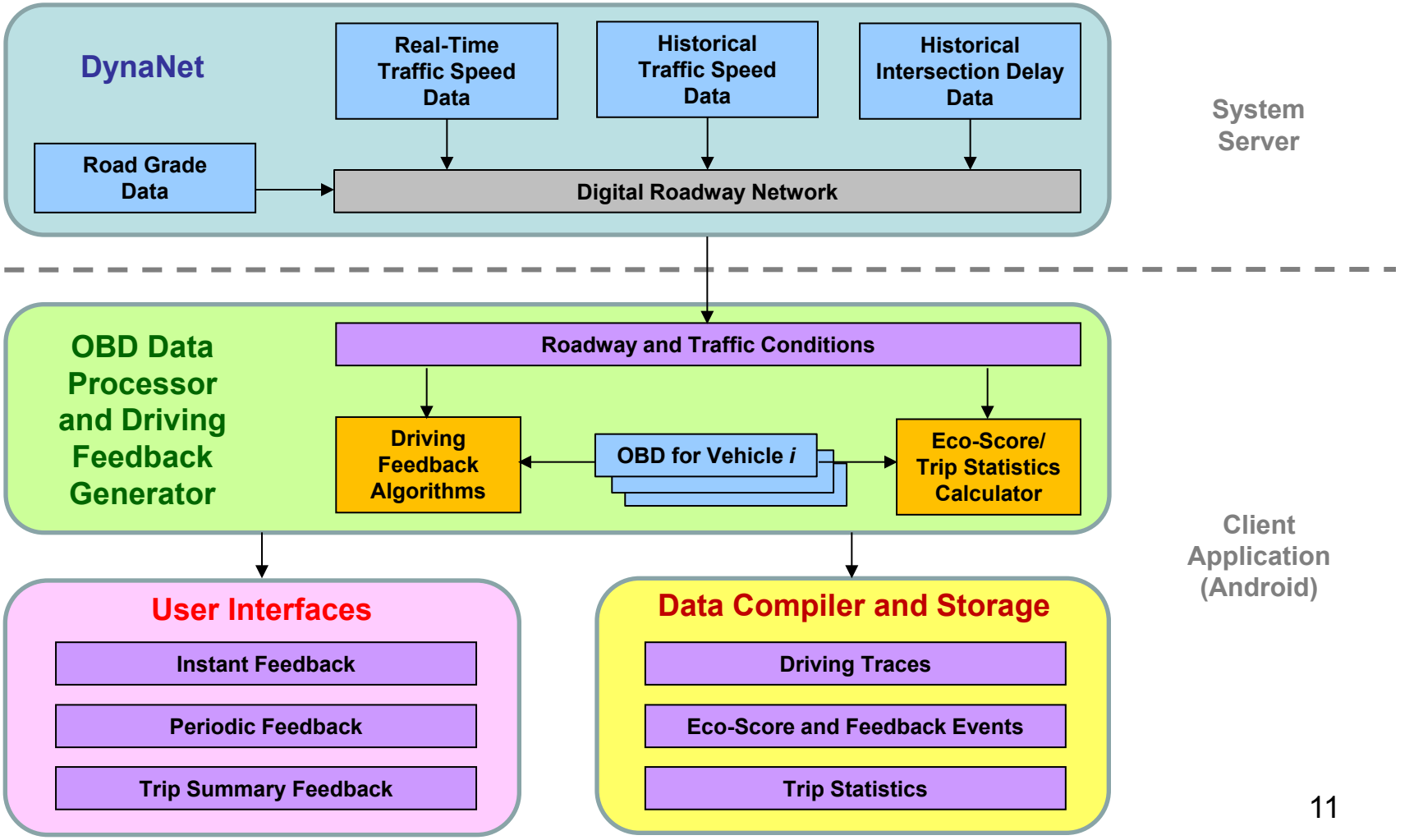
Time	29.2	36.2	0.92 $3.82	
Fuel	27.4	43.1	0.85 $3.53	
Carbon Monoxide	28.5	60.3	0.93 $3.89	

With Intersection Delays

Time	29.2	38.8	1.06 $4.41	
Fuel	28.4	42.1	1.04 $4.35	
Carbon Monoxide	28.7	63.6	1.22 $5.08	

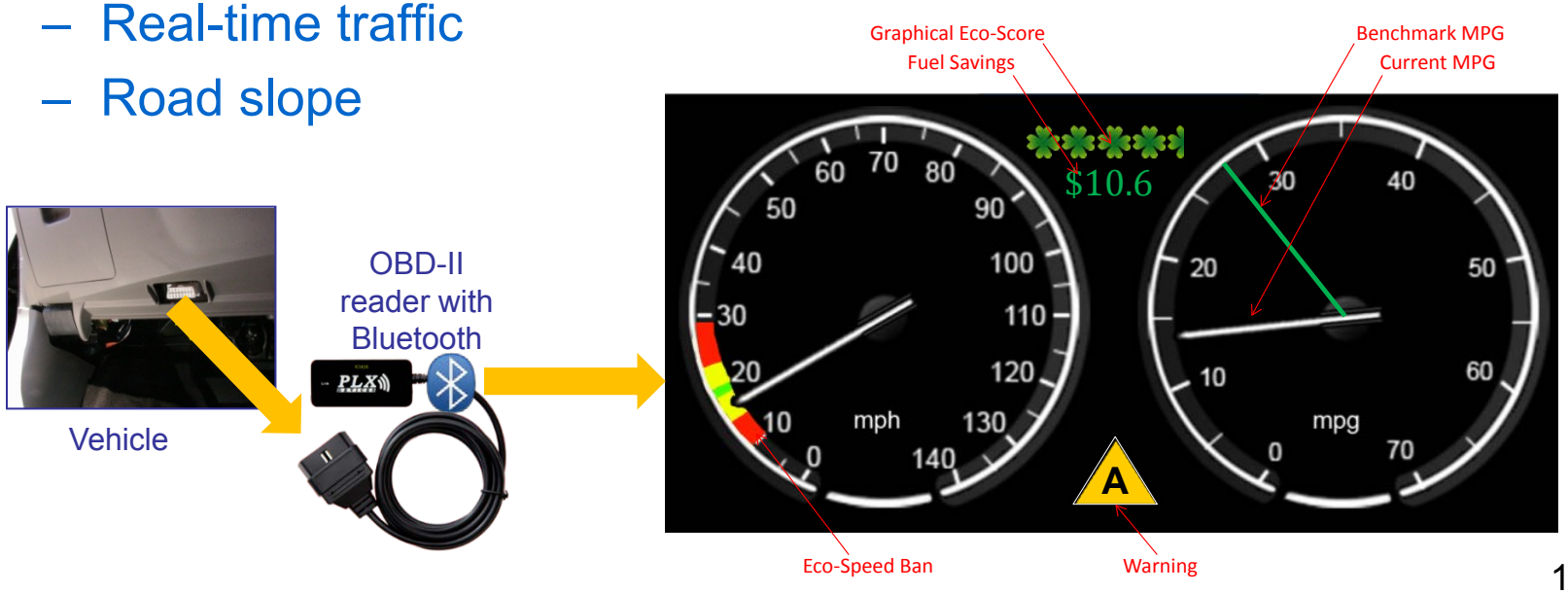
Technical Accomplishments (4)

- Eco-Driving Feedback module – software architecture



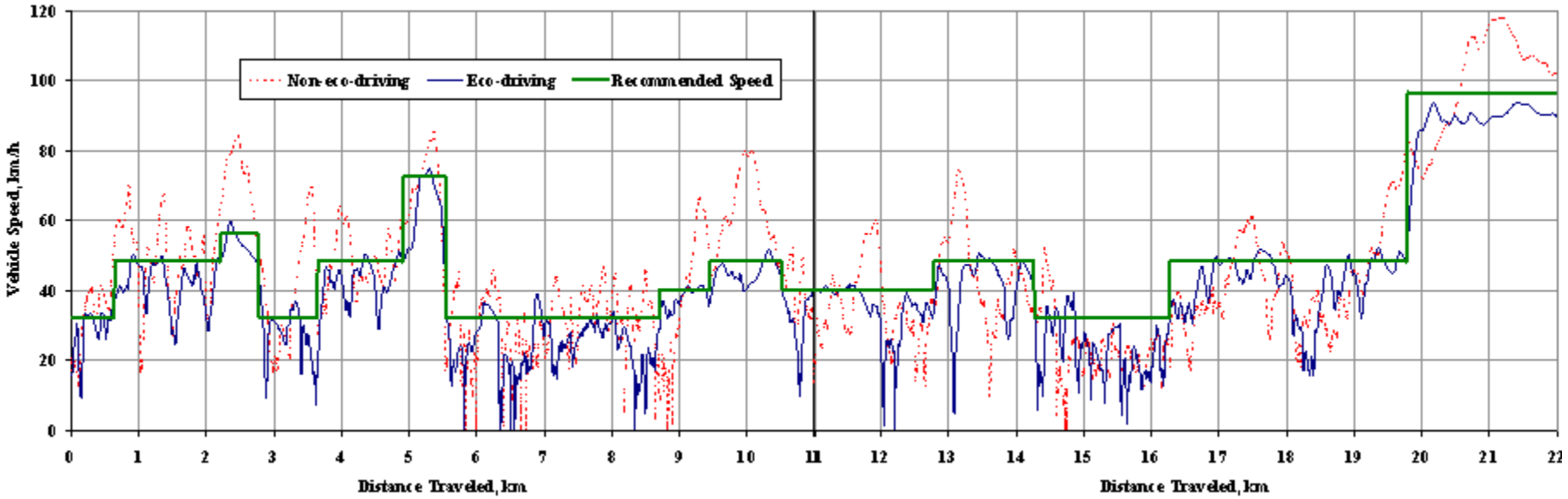
Technical Accomplishments (5)

- Eco-Driving Feedback module – user interfaces
- Simple and intuitive; similar to current vehicle dashboard, which should help reduce “eyes-off-road” time
- Feedback determined based on:
  - Actual fuel use (from vehicle’s OBD-II)
  - Real-time traffic
  - Road slope



Technical Accomplishments (6)

- Eco-Driving Feedback module – effect of eco-speed

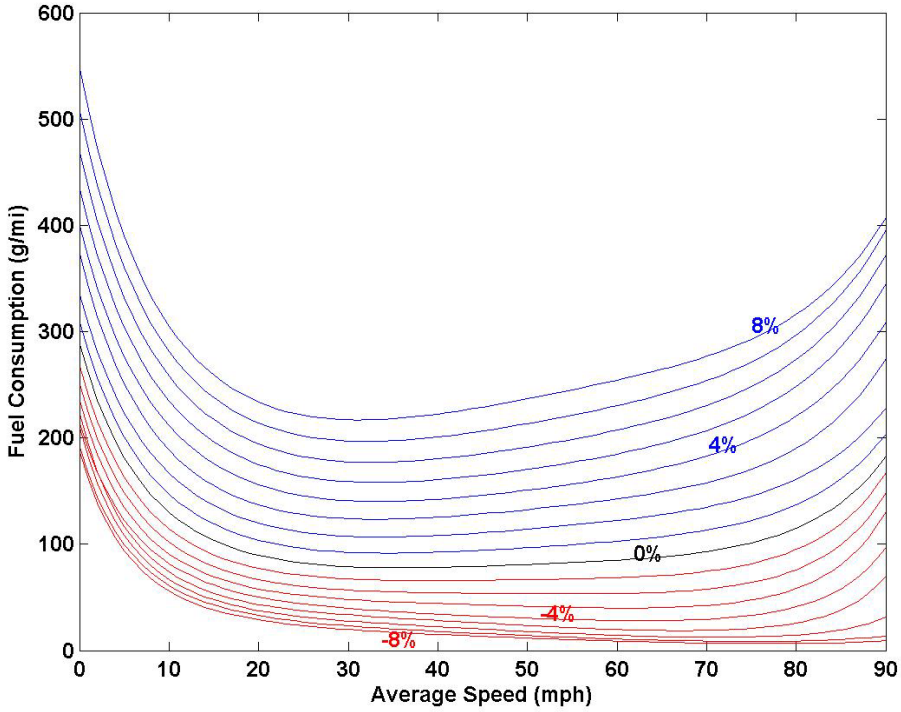


Real-world experiment on SR-91 in Southern California shows fuel savings of 13% for the eco-driving vehicle.

Energy/Emissions	Non Eco-Driving	Eco-Driving	Difference
Fuel (g)	1766	1534	-13%
CO2 (g)	5439	4781	-12%
CO (g)	97.01	50.47	-48%
HC (g)	3.20	1.90	-41%
NOx (g)	6.28	3.97	-37%
Travel time (min)	38.9	41.2	+6%

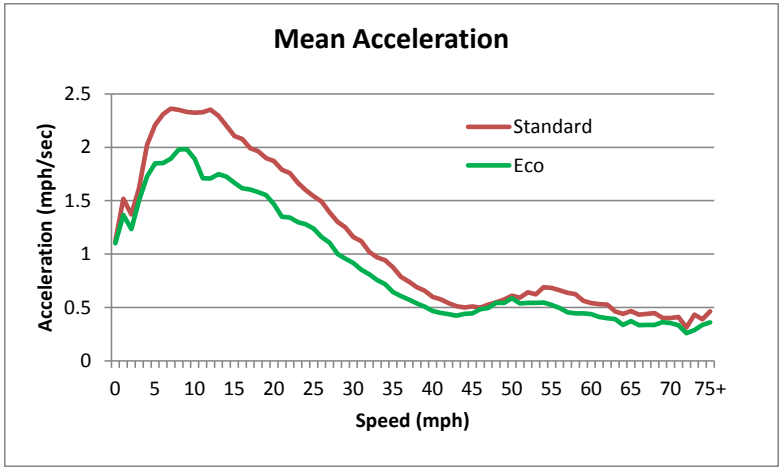
Technical Accomplishments (7)

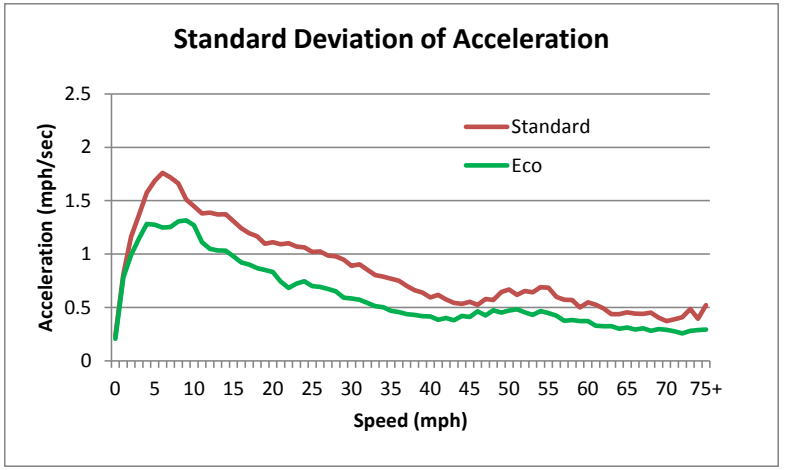
- Eco-Driving Feedback module – effect of road slope
- Sweet-spot speeds vary by road slope.
- Eco-speed is adjusted based on road slope.
  - Lower when on uphill
  - Higher when on downhill



Technical Accomplishments (8)

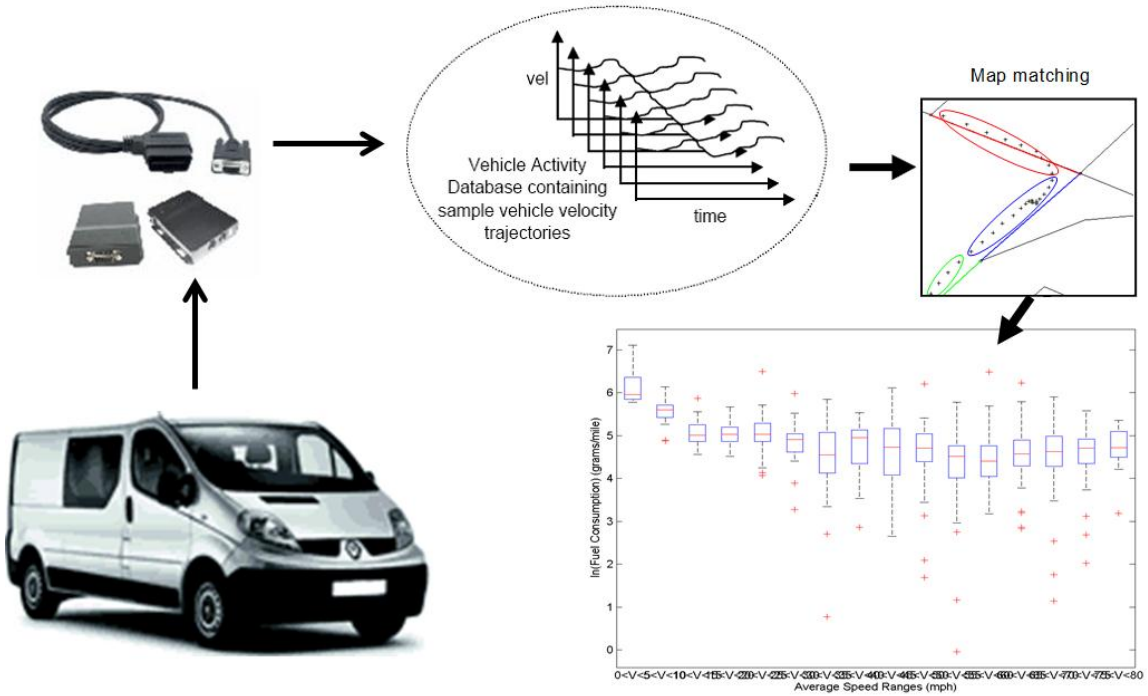
- Eco-Driving Feedback module – aggressive acceleration warning
- Typical acceleration rates vary by speed
  - Higher mean at lower speeds
  - Higher standard deviation at lower speeds
- Warning provided when exceeding the preset acceleration rate for a speed (e.g., $\mu + 2\sigma$)





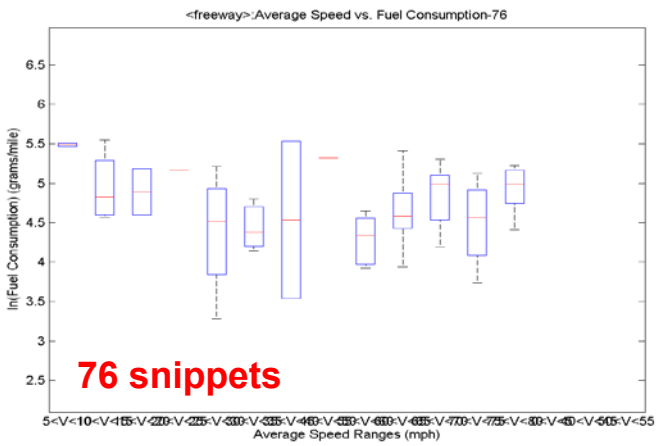
Technical Accomplishments (9)

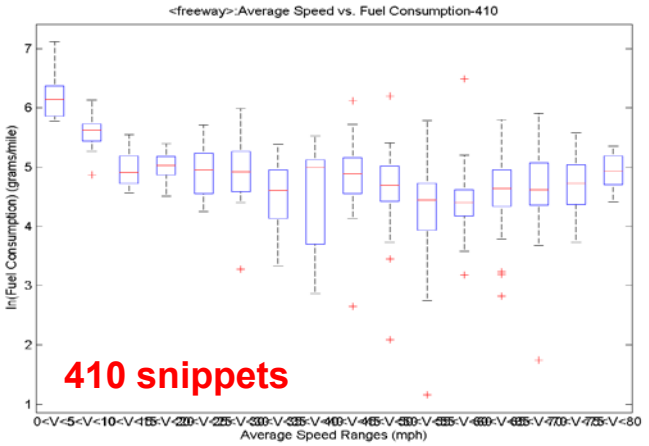
- Algorithm updating module automatically generates and continuously self-updates fuel consumption curves based on real-world fuel consumption data from the vehicle's OBD-II
- Adapt to changing driver behavior (as he eco-drives) and vehicle performance (as it wears out) over time

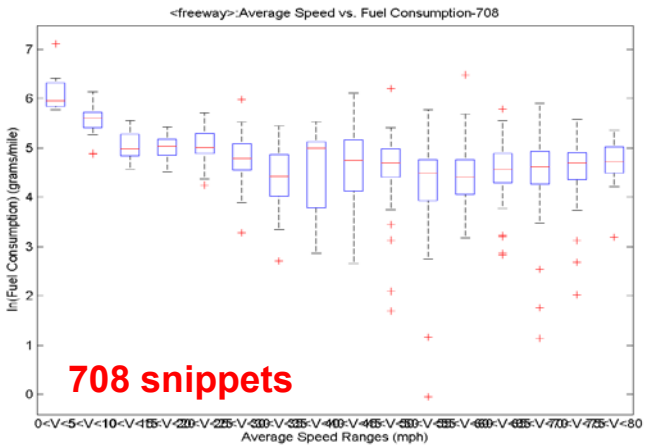


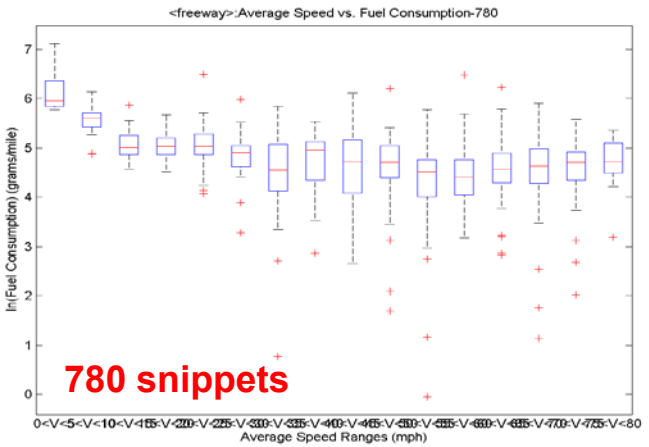
Technical Accomplishments (10)

- Algorithm Updating module – progression of median curve



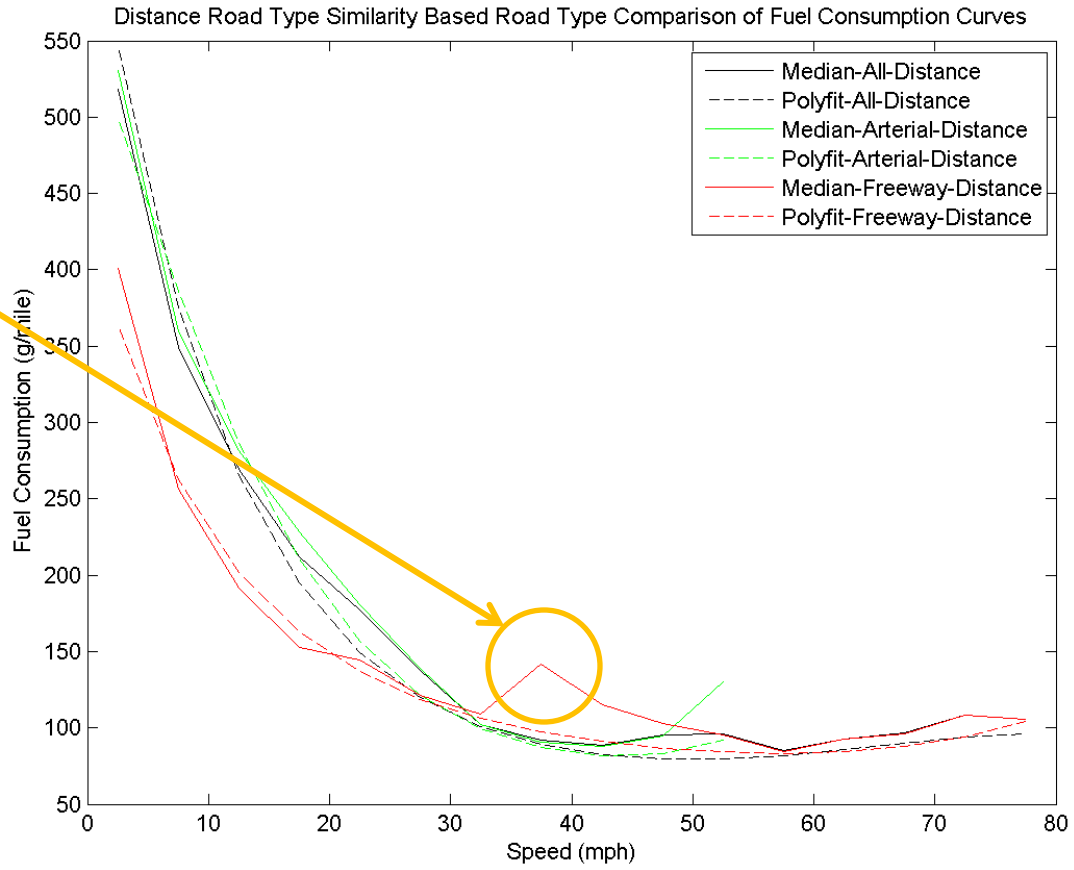






Technical Accomplishments (11)

- Algorithm Updating module – comparison with fitted curve
- Trends of the median and fitted curves are similar.
- Median curve better captures fuel rate characteristic under transient traffic condition.
- At the same speed under 25 mph, driving on freeway consumes less fuel.



Collaborations & Coordination (1)

- Collaborations within the project
  - U. of California Riverside (university; prime contractor)
    - Conduct system R&D, lead system testing & evaluation
  - Esri (industry)
    - Provide trip scheduling & GIS software and technical support
  - NAVTEQ (industry)
    - Provide 3D digital map and real-time & historical traffic data
  - Beat the Traffic (small-business enterprise)
    - Model intersection delays using smartphone-based GPS data
  - Earthrise Technology (small-business enterprise)
    - Develop OBD-II interface software and provide technical support
  - Automatiks (small-business enterprise)
    - Configure connectivity between in-vehicle device and system server

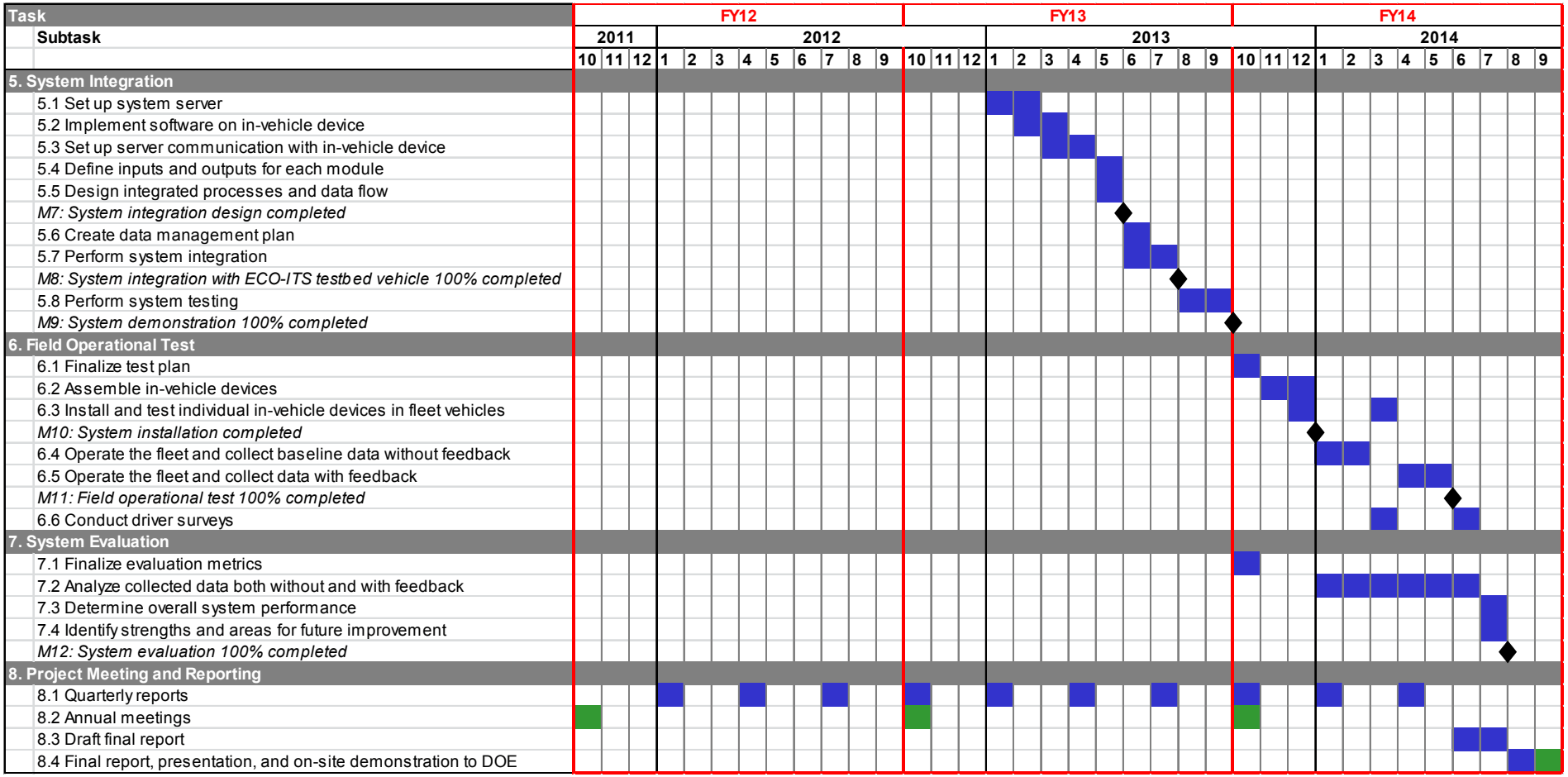
Collaborations & Coordination (2)

- Collaborations within the project (continued)
  - Riverside Transit Agency (local government)
    - Provide fleet and staff support for system field operational test
  - California Department of Transportation (state government)
    - Provide fleet and staff support for system field operational test
  - University of California Berkeley (university)
    - Conduct expert interviews and drivers' perception surveys
- Coordination with other research programs
  - Eco-Driving research of the U. of California's Multi-campus Research Program and Initiative (MRPI)
  - Applications for the Environment: Real-Time Information Synthesis (AERIS) research of the Federal Highway Administration

Collaborations & Coordination (3)

- Collaborations outside the project
  - Worked with Nissan to develop method for quantifying fuel saving/GHG reduction benefits of eco-driving technologies
  - Interviewed 11 experts to obtain inputs for system design
    - California Department of Transportation [fleet management]
    - Daimler Trucks [R&D]
    - Environmental Protection Agency (2 experts) [policy]
    - Environmental systems Research Institute [R&D]
    - General Motors [R&D]
    - National Renewable Energy Laboratory [R&D]
    - Riverside Transit Agency [fleet management]
    - Westat [consulting]
    - University of Minnesota, HumanFIRST Program [R&D]
    - U.S. Department of Transportation [policy]

Proposed Future Work

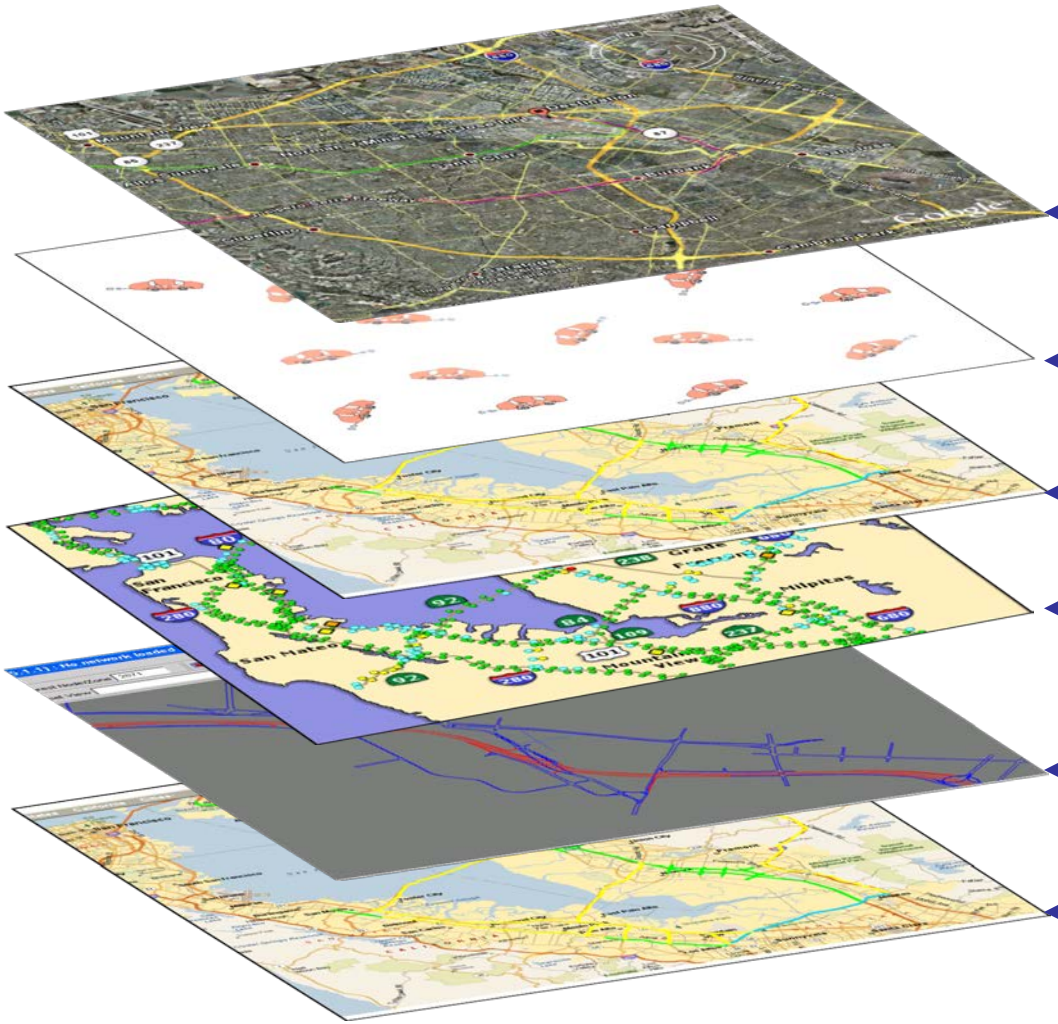


Summary

- Project objectives over the past year have been achieved – three system modules completed.
  - Eco-Routing Navigation module
  - Eco-Driving Feedback module
  - Algorithm Updating module
- Initial testing of the individual modules shows promising results.
- The research team has tried to expand coordination of this DOE project with other research programs that target vehicle fuel efficiency improvements.
- The research team is well positioned for work planned next year.

Technical Back-Up Slides

Dynamic Roadway Network (DynaNet)



Google Earth or Google Maps interfaces

Real-time probe vehicle data (for freeways and surface streets)

Real-time data from other sources

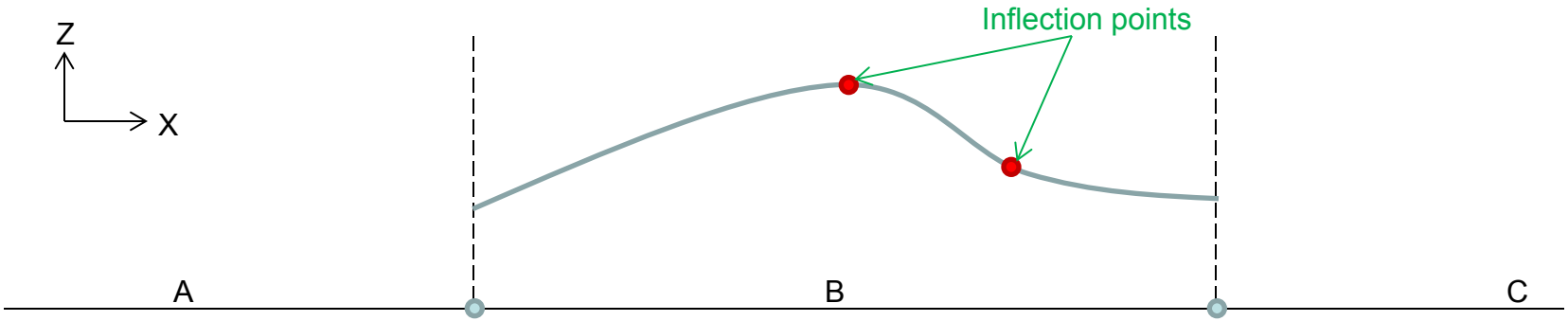
Real-time PeMS data (for freeways)

Historical data from travel demand or traffic simulation models

Underlying digital roadway network with speed limit info

Road Grade Integration

- One 2D link may have multiple road grade values

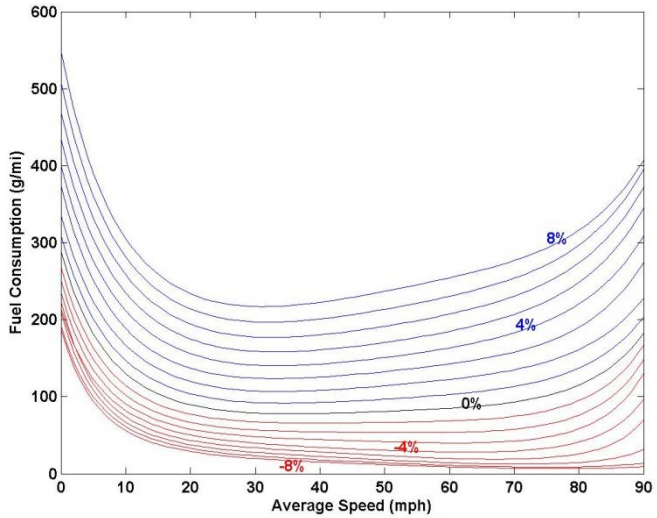


- Referring to sublinks by their sequences in the link
  - For more accurate link fuel consumption calculation
  - Does not increase the number of links in the shortest path calculation

Link_ID	Sequence_Number	Distance	Grade
23593103	1	10.106039718...	537
23593103	2	26.005687704...	524
23593103	3	62.582112643...	377
23593560	1	67.28965307	-2391
23593562	1	29.981222438...	-1491
23593562	2	37.464598654...	-2333
23593563	1	14.948617045...	-5553
23593563	2	12.955798930...	-4963
23593563	3	40.951709691...	-3987

Link Fuel Consumption Calculator (1)

- Step 1 – Convert EOPS curves into a look-up table.



Grade

Speed	-8%	-7%	…	-1%	0%	1%	…	7%	8%
0									
1									
2									
3									
4									
5									
…									
79									
80									

- Step 2 – For each link *k* with n_k sublinks, calculate fuel consumption for each speed value *v*.

$$F_k(v) = \sum_{i=1}^{n_k} [f(v, g_i) \cdot d_i]$$

F = fuel consumption (grams)

f = fuel consumption rate (grams/mile)

d = distance (miles)

Link Fuel Consumption Calculator (2)

Fuel Consumption Rate Table

SpeedBin	RoadGrade	Cost
0	-8	187.238095
0	-7	192.457118
0	-6	210.402039
0	-5	224.123047
0	-4	214.048577
0	-3	235.82528
0	-2	251.387097
0	-1	268.351557
0	0	289.247159
0	1	309.971344
0	2	335.693929
0	3	374.249271
0	4	400.709434
0	5	435.071333
0	6	470.510999
0	7	508.995504
0	8	549.376415
1	-8	160.519417
1	-7	166.121024
1	-6	181.076072
1	-5	193.312287

Road Grade Table

Link_ID	Sequence_Number	Distance	Grade
23593103	1	10.106039718...	537
23593103	2	26.005687704...	524
23593103	3	62.582112643...	377
23593560	1	67.28965307	-2391
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23593563	1	14.948617045...	-5553
23593563	2	12.955798930...	-4963
23593563	3	40.951709691...	-3987
23593564	1	17.862474289...	-5281
23593564	2	41.914402483...	-5373
23593713	1	26.972987721...	-3145
23593713	2	31.611308980...	-2475
23593715	1	126.709219131	-244
23593729	1	26.131533565...	1843
23593729	2	28.673477730...	1928
23593730	1	16.993153151...	1623
23593730	2	49.836216191...	1898

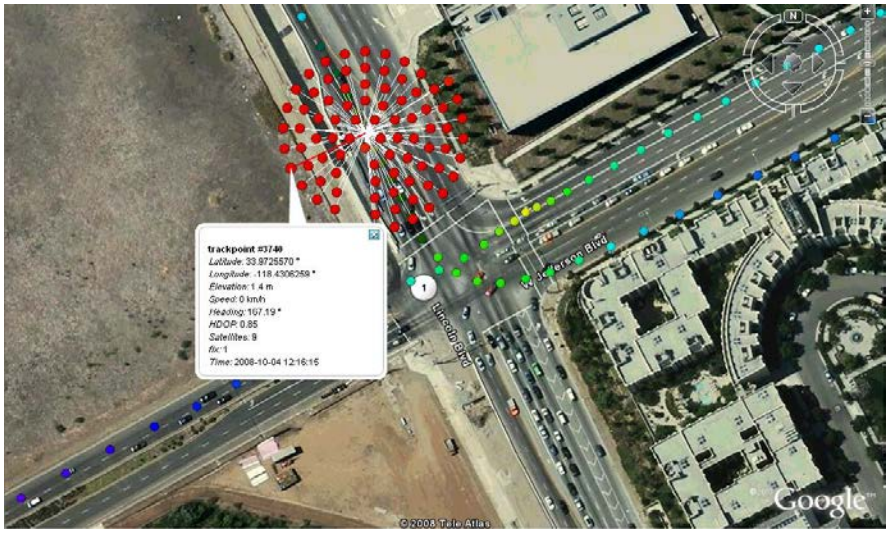
Link Fuel Consumption Table

SourceID	OID	Speed_1	Speed_2	Speed_3	Speed_4	Speed_5	Speed_6	Speed_7	Speed_8	Speed_9	Speed_10
1	1	32.477308	29.411779	26.797038	24.556708	22.629101	20.964109	19.520811	18.265614	17.170802	16.213392
1	2	27.525607	24.927468	22.711387	20.812633	19.178922	17.767785	16.544541	15.48072	14.55283	13.741393
1	3	12.28586	11.126199	10.137067	9.289572	8.560376	7.930525	7.384539	6.90971	6.495553	6.133373
1	4	12.439966	11.265759	10.26422	9.406094	8.667752	8.030001	7.477166	6.996381	6.577029	6.210307
1	5	84.139714	76.197778	69.423706	63.619633	58.625737	54.312203	50.573017	47.32115	44.484794	42.004409
1	6	8.03816	7.279439	6.632288	6.077805	5.600721	5.188634	4.831416	4.520754	4.249787	4.012827
1	7	13.809019	12.505587	11.393826	10.441261	9.621662	8.913725	8.300049	7.766352	7.300849	6.893768
1	8	41.921622	37.964645	34.589544	31.697733	29.209583	27.060415	25.19741	23.577206	22.164025	20.928202
1	9	15.241235	13.802617	12.575548	11.524187	10.619582	9.83822	9.160897	8.571847	8.058064	7.608762
1	10	16.0196	14.507512	13.217777	12.112723	11.161921	10.340655	9.628741	9.009608	8.469587	7.997339
1	11	6.493281	5.880381	5.357608	4.909693	4.524301	4.191414	3.902852	3.651897	3.433008	3.24159
1	12	12.720456	11.519774	10.495652	9.618178	8.863188	8.211057	7.645757	7.154132	6.725324	6.350333
1	13	4.149333	3.757678	3.423616	3.137389	2.891116	2.678395	2.493998	2.333633	2.193758	2.071439
1	14	8.352052	7.563703	6.891281	6.315145	5.81943	5.391251	5.020084	4.697291	4.415742	4.169529
1	15	2.931201	2.654526	2.418535	2.216337	2.042363	1.892091	1.761828	1.648542	1.549731	1.463321
1	16	7.854003	7.112665	6.480341	5.938561	5.472407	5.069761	4.720727	4.417183	4.152424	3.920892
1	17	24.445412	22.138013	20.169918	18.48364	17.032745	15.779519	14.69316	13.748383	12.924327	12.203691
1	18	15.873327	14.375046	13.097088	12.002124	11.060003	10.246236	9.540822	8.927343	8.392252	7.924317
1	19	13.3725	12.110271	11.033654	10.111201	9.31751	8.631951	8.037675	7.520849	7.070061	6.675848
1	20	28.125995	25.471186	23.206768	21.266598	19.597252	18.155336	16.905411	15.818386	14.870256	14.04112
1	21	26.377985	23.888171	21.764484	19.944895	18.379297	17.026995	15.854752	14.835285	13.946081	13.168475
1	22	25.847219	23.407503	21.326549	19.543572	18.009477	16.684385	15.535729	14.536775	13.665464	12.903504
1	23	7.455193	6.751498	6.151282	5.637013	5.194529	4.812328	4.481018	4.192887	3.941572	3.721797
1	24	10.68743	9.678645	8.818202	8.080968	7.446643	6.898738	6.423787	6.010734	5.65046	5.335402
1	25	16.300637	14.762022	13.449661	12.32522	11.357738	10.522064	9.797661	9.167667	8.618171	8.137639
1	26	19.72785	17.865741	16.277456	14.916601	13.745706	12.734331	11.857622	11.095171	10.430144	9.84858
1	27	4.106343	3.718746	3.388145	3.104884	2.861163	2.650645	2.468159	2.309455	2.17103	2.049978
1	28	14.665338	13.281079	12.100375	11.08874	10.218317	9.466479	8.814748	8.247956	7.753586	7.321262
1	29	14.801003	13.403938	12.212312	11.191319	10.312843	9.55405	8.896291	8.324255	7.825312	7.388988
1	30	50.97456	46.163078	42.059126	38.542831	35.517368	32.904089	30.638769	28.668683	26.950327	25.44763
1	31	29.290412	26.525694	24.167529	22.147036	20.408579	18.906967	17.605295	16.473267	15.485885	14.622423
1	32	3.046389	2.758841	2.513577	2.303433	2.122622	1.966445	1.831063	1.713325	1.610631	1.520825
1	33	16.155936	14.63098	13.330268	12.21581	11.256916	10.42866	9.710687	9.086286	8.541668	8.065401
1	34	16.645788	15.074594	13.734445	12.586196	11.598228	10.74486	10.005118	9.361784	8.800653	8.309946
1	35	41.61385	37.685924	34.335601	31.465021	28.995138	26.861749	25.012421	23.404111	22.001305	20.774556
1	36	7.825808	7.087131	6.457077	5.917242	5.452761	5.051561	4.70378	4.401325	4.137517	3.906817
1	37	15.817489	14.324478	13.051015	11.959903	11.021097	10.210192	9.50726	8.895939	8.36273	7.896441
1	38	12.707393	11.507944	10.484874	9.608301	8.854086	8.202625	7.637906	7.146785	6.718418	6.343812
1	39	15.102141	13.676652	12.460781	11.419015	10.522666	9.748435	9.077293	8.493619	7.984525	7.539323
1	40	7.267821	6.581812	5.996682	5.495337	5.063975	4.69138	4.368397	4.087507	3.842508	3.628257
1	41	23.649531	21.417255	19.513236	17.881859	16.478202	15.265777	14.214787	13.30077	12.503543	11.80637
1	42	13.818897	12.514533	11.401977	10.44873	9.628545	8.920101	8.305986	7.771908	7.306072	6.8987
1	43	12.395573	11.225557	10.227591	9.372528	8.63682	8.001345	7.450483	6.971414	6.553558	6.188145
1	44	12.395573	11.225557	10.227591	9.372528	8.63682	8.001345	7.450483	6.971414	6.553558	6.188145
1	45	9.903452	8.968667	8.171342	7.488188	6.900394	6.39268	5.952569	5.569816	5.23597	4.944023
1	46	9.819638	8.892764	8.102186	7.424814	6.841995	6.338578	5.902192	5.522678	5.191657	4.902181
1	47	26.931632	24.389559	22.221298	20.363517	18.76506	17.384374	16.187527	15.146662	14.238795	13.444867
1	48	16.456812	14.903456	13.578521	12.443307	11.466556	10.622875	9.891531	9.255502	8.700741	8.215605

Excessive Idle Warning

268-second idling at an activity location

85-second idling at a signalized intersection



- Need to differentiate idling events
  - Discretionary (e.g., at trip starts, trip ends, activity locations)
  - Non-discretionary (e.g., at traffic lights)
- Literature suggests a threshold of 120 seconds.